Pixel 2008
Fermilab

Commissioning of The CMS Forward Pixel Detector

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Snapshots

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- Commissioning at Tracker Integration Facility at CERN
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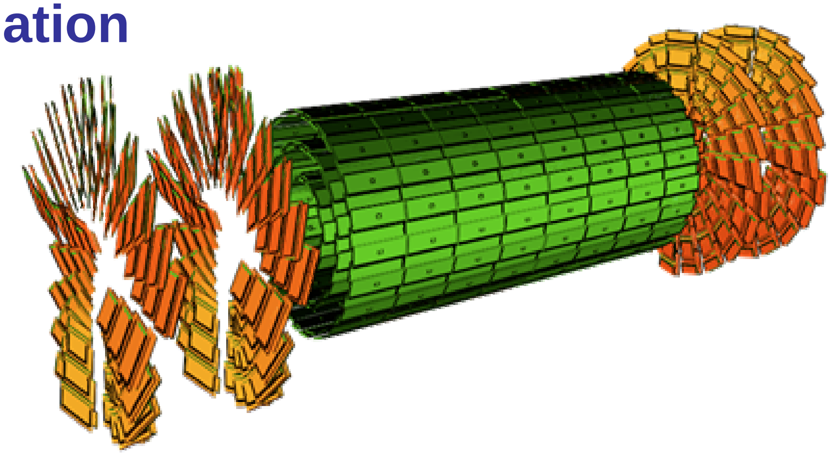
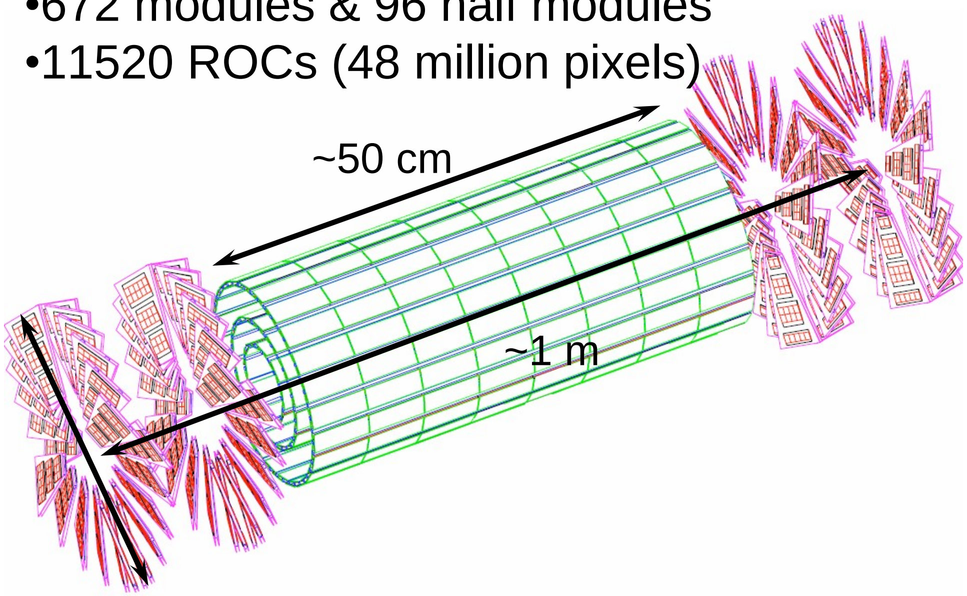
- Summary



Pixel System Overview

Barrel Pixels

- 3 barrel layers at *r* of 4.3, 7.3 and 10.4 cm
- 672 modules & 96 half modules
- 11520 ROCs (48 million pixels)

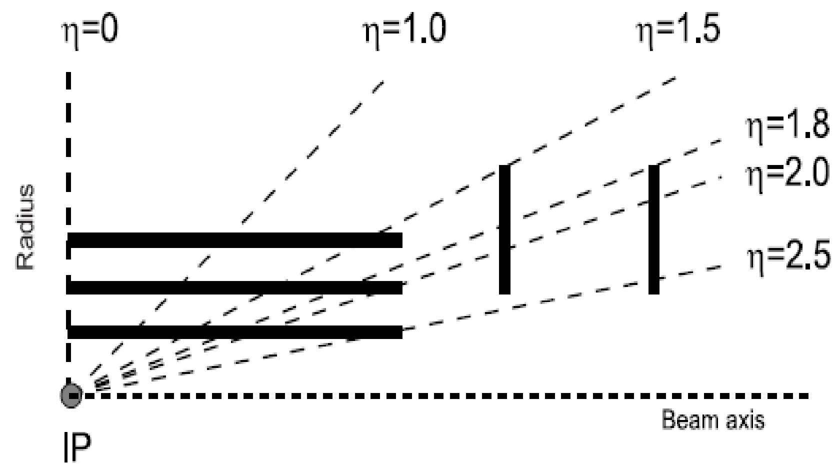


Forward Pixels

- 4 disks at *z* = ±34.5 & ±46.5 cm
- Extend from 6-15 cm in radius
- 672 modules in 96 blades
- 4320 ROCs (18 million pixels)

The design allows for three high precision tracking points up to |η| of ~2.5, essential for

1. reconstruction of secondary vertices from b & τ decays
2. forming seed tracks for the outer track reconstruction and high level triggering



Pixel System Overview

Active area:

-- 0.78 m^2(BPIX), 0.28 m^2 (FPIX) as compared to ~200 m2 for Silicon Strips

-- but 7 times more readout channels.

Challenging environment:

Being at front seat facing the beam interactions, it is subjected to very high track rate and extremely harsh radiation that require a radiation tolerant design $\Rightarrow$ sensor with n+ pixel on n-substrate design allows for partial depleted operation even at very high particle fluences.

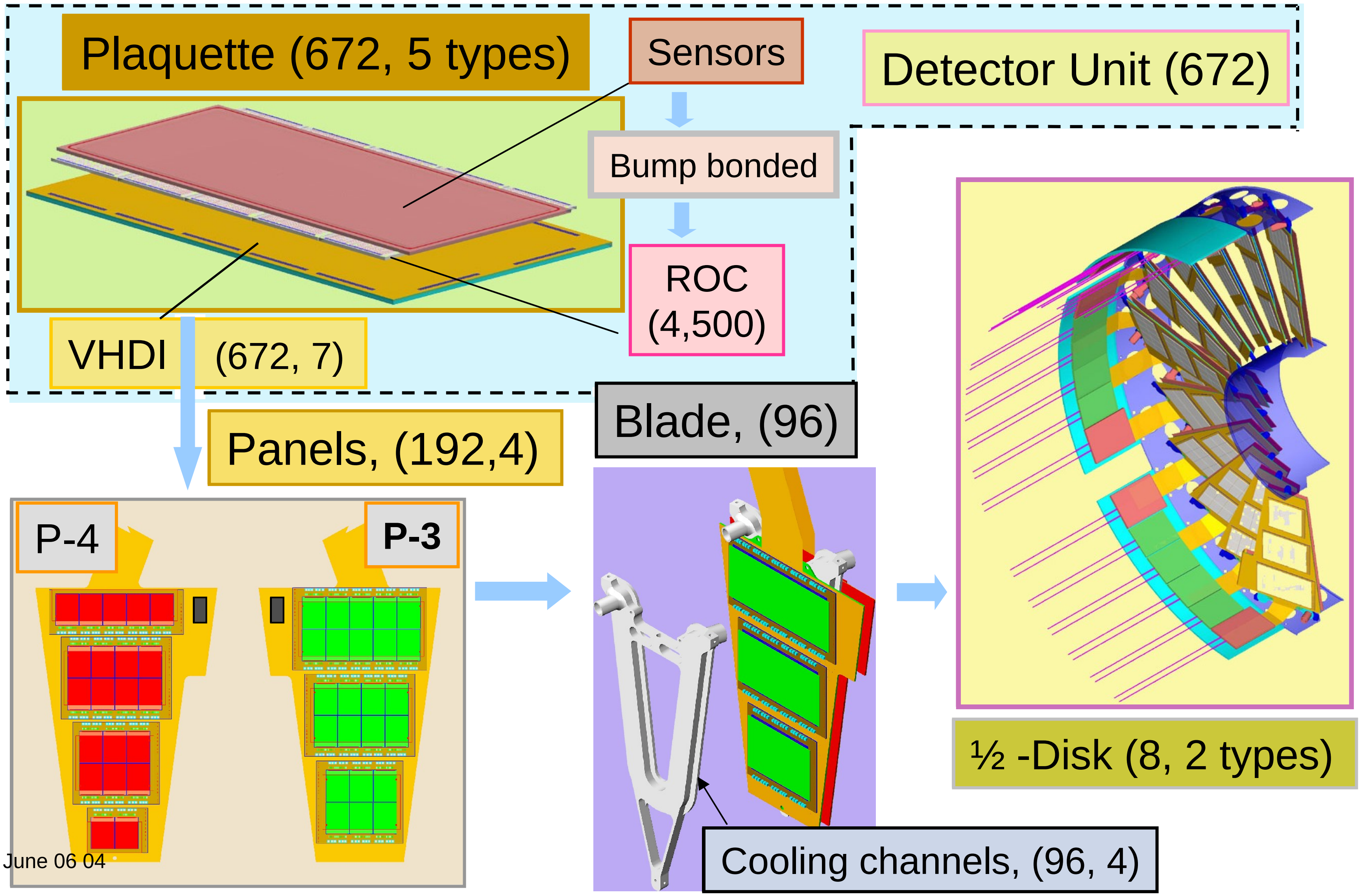
Spatial Resolution:

-- with pixels of 150μm x100 μm, hit resolution of 15-20 μm expected due to charge sharing among neighboring pixels in the presence of 4T magnetic field.

-- **BPIX:** charge sharing induced by Lorentz drift

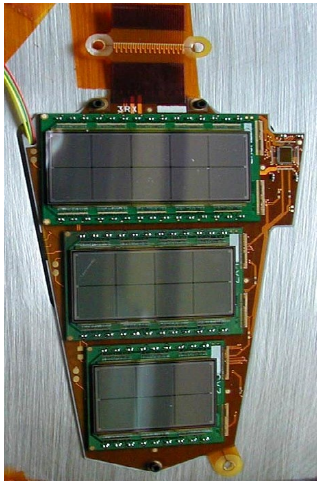
-- **FPIX :** a tilted (turbine) geometry of 20° was chosen to induce charge sharing due to non zero incident angle of particles entering the detector.

FPix Detector Components



FPix Detector Components

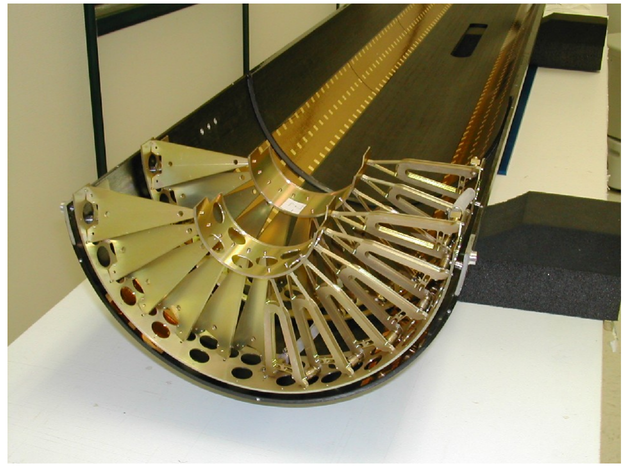
Panel



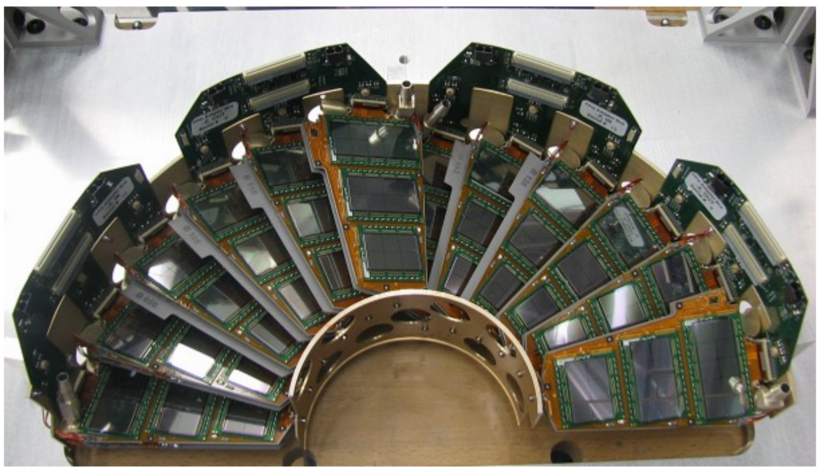
Plaquettes

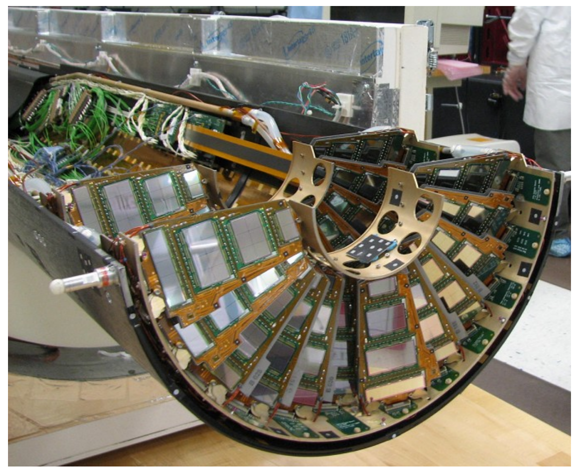
½-Disk

1/2-service cylinder

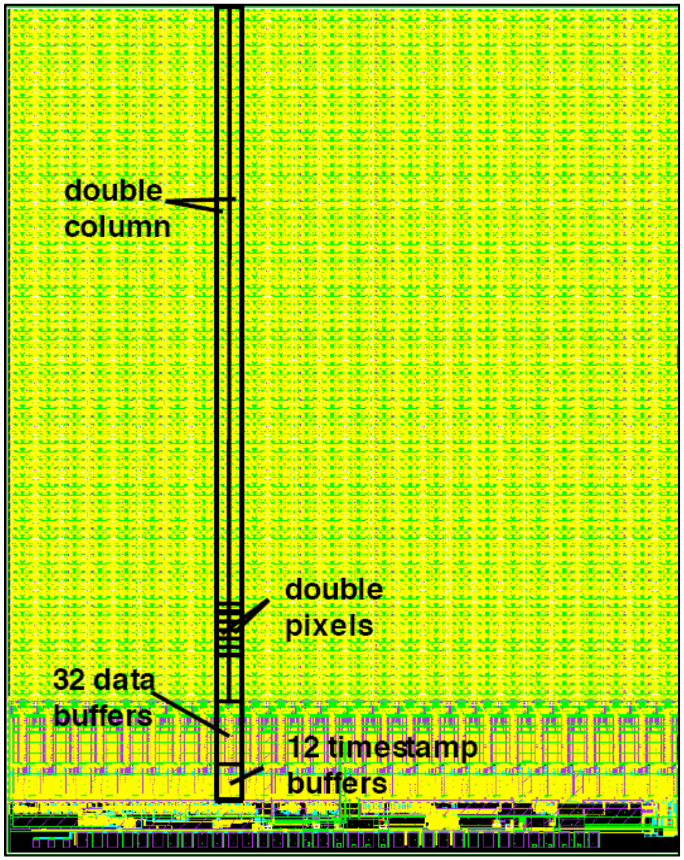


Fully populated

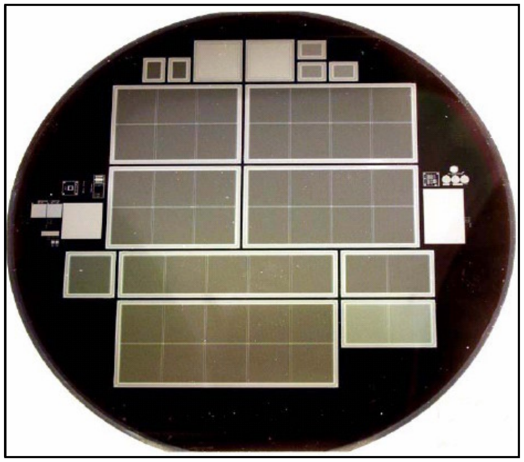




Readout Chips & Sensors



- 0.25µm IBM CMOS radiation tolerant
- 100x150 μm^2 pixel cell size:
  - ✓Maximum occupancy ~0.033% at full LHC luminosity
- 52x80 cells organized in double columns
- Pixels have amplifier, shaper, discriminator, capacitor & charge injection circuitry for calibration purposes
- 120 mW/ROC power draw
- Highly tunable (28 DACs)
- Analog readout with zero suppression. Readout of position & pulse height encoded on 6 analog levels.



- design: n+ on n-type with p-stop isolation
- bulk width: ~270 µm
- bump bonded to the ROCs using PbSn

Module Assembly & Testing

1. Assembly & quick testing of modules at Purdue University → Fermilab

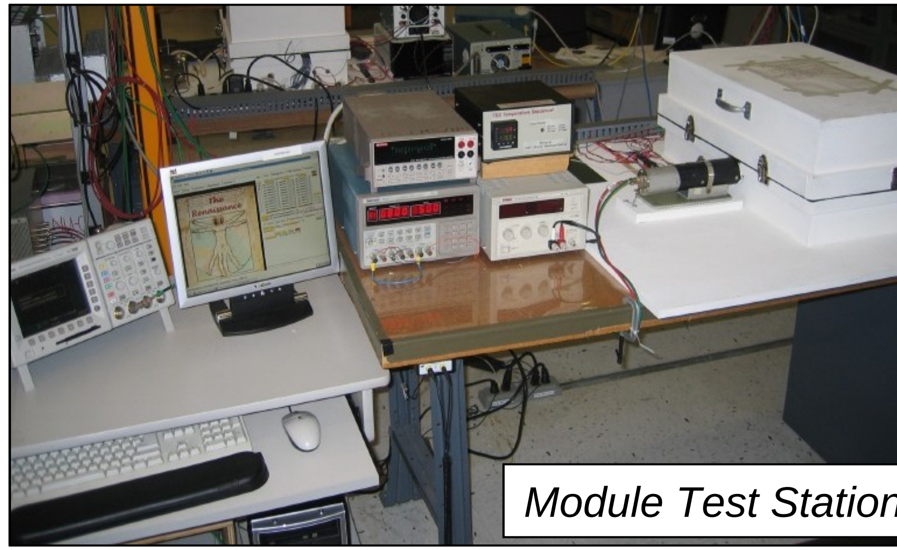
2. At Fermilab, the modules subjected to two-day thermal cycling process consisting of 10 cycles between +20 and -15°C

3. Since the detector will operate at cold temperatures to minimize the effects of radiation damage, modules underwent detailed testing & characterization at -15°C

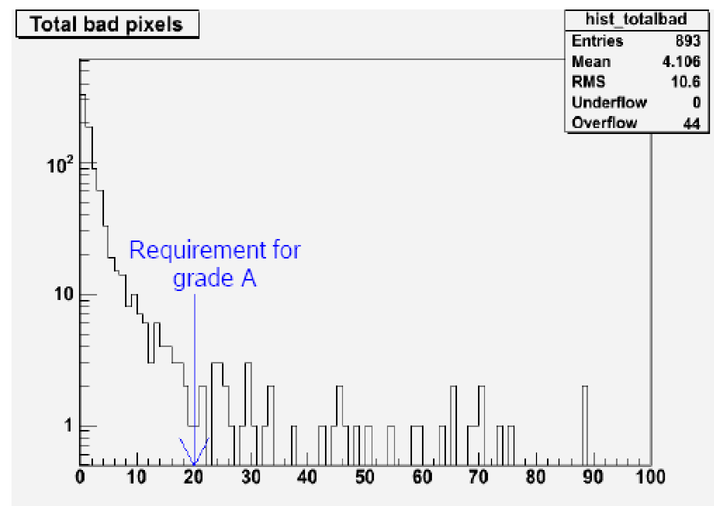
   -- measurement of IV characteristics of sensor, detection of dead pixels & missing bump bonds, measurement of threshold & gain curve for each pixel.

4. Panel assembly from plaquettes determined to be of sufficiently good quality.

5. Mounting of panels on the half disks.



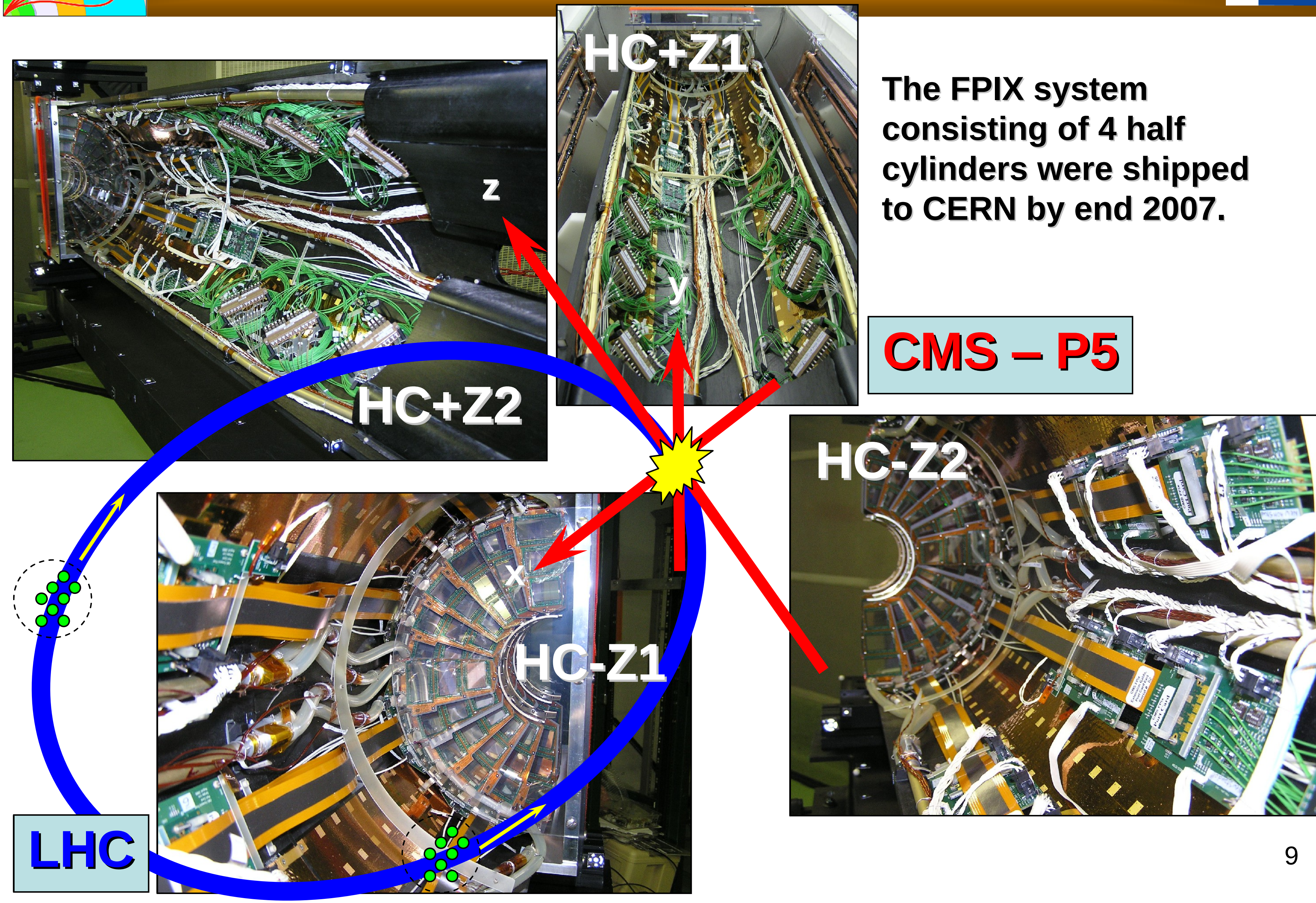
Module Test Station



Mount 2 half disks & electronics in the 1/2 service cylinder to be tested with the final DAQ electronics, before being shipped to CERN for commissioning

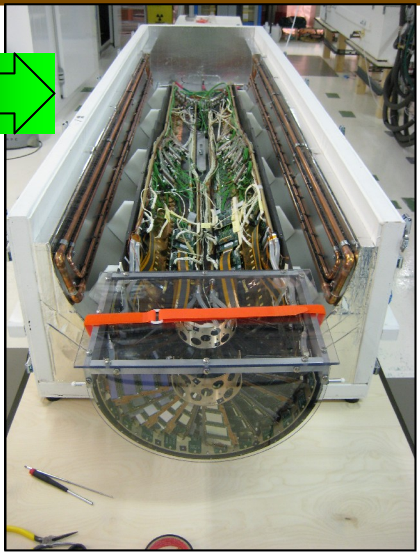
Complete FPix Detector

The FPIX system consisting of 4 half cylinders were shipped to CERN by end 2007.



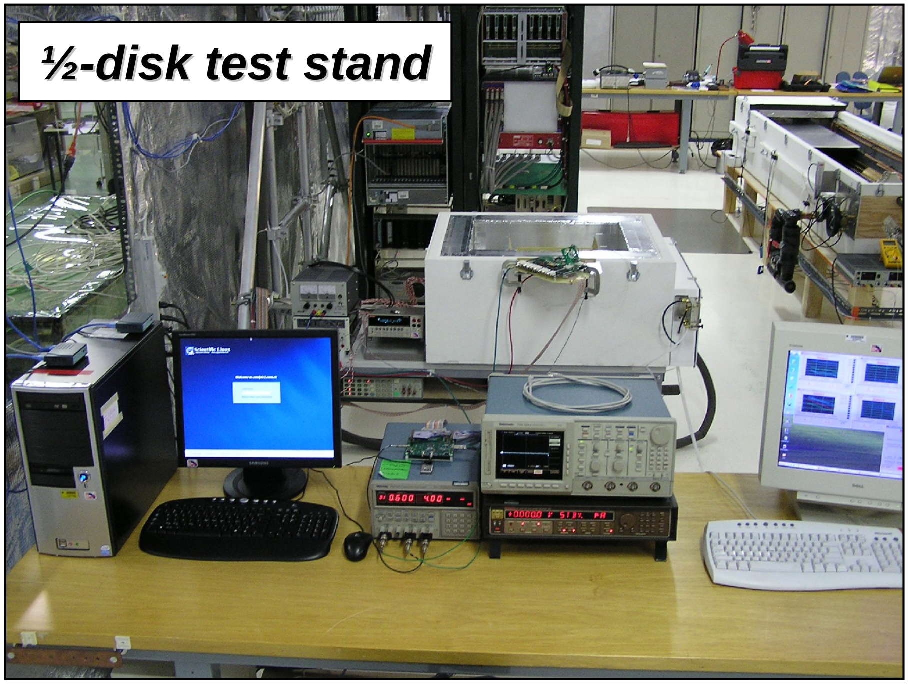
FPix Commissioning at CERN

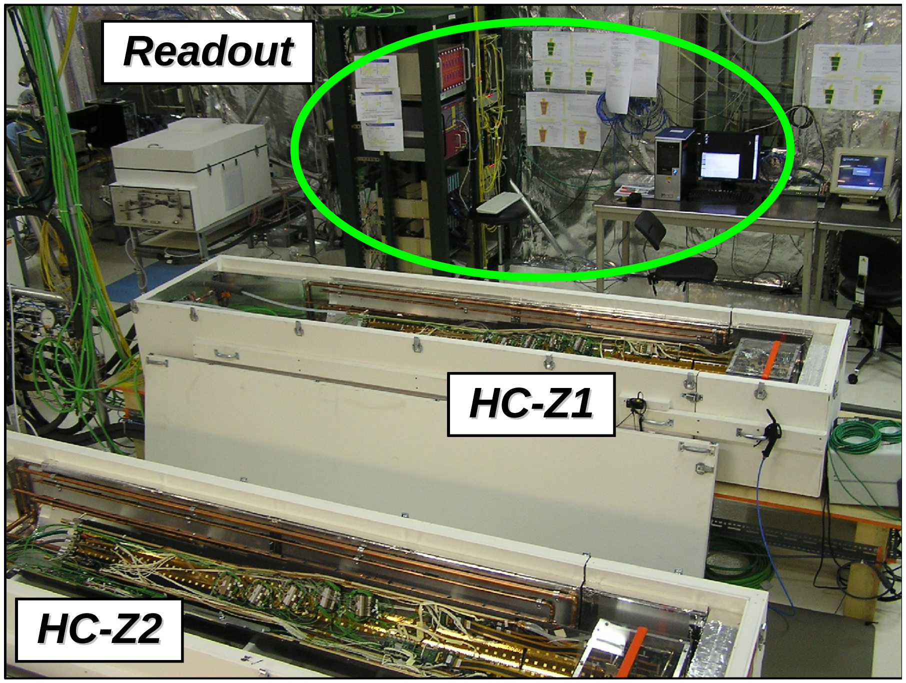
The ½-disks and the ½-service cylinders were reassembled at the CERN Pixel clean room where they underwent extensive system tests.



•Experiment-like systems for the safety, control, power and data acquisition were implemented to commission the detector prior to final installation into CMS.

•An engineering FPIX detector (equivalent to ~4% of the full system) was also built to pioneer all of the assembly and testing procedures





Commissioning Strategy

Aim: Thoroughly test and check both electrical and mechanical aspects of the system and comparison of general performance with that obtained at Fermilab.

-- all connections: wires, fibers, pipes, RTDs, humidity sensor, boards etc.

-- absence of leaks in the cooling circuit

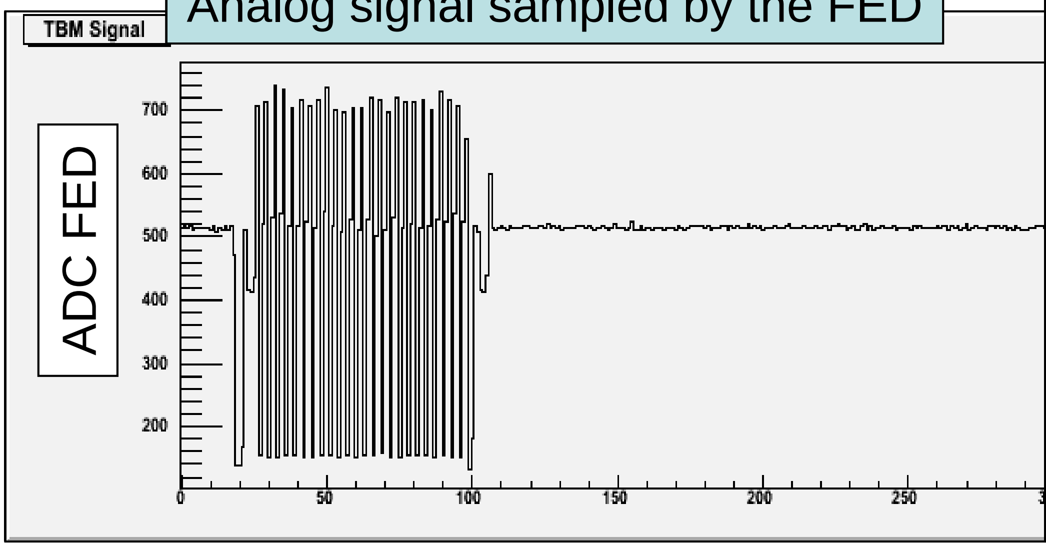
-- mapping and cleanliness of optical fibers

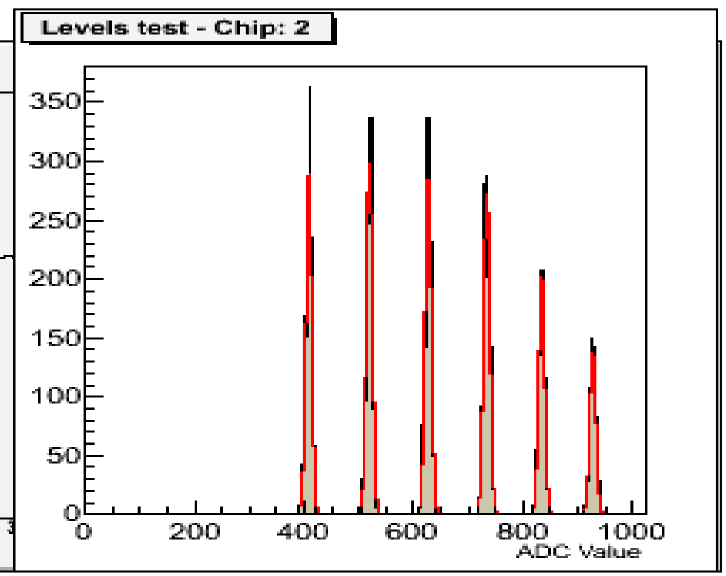
-- mapping of sensors for detector control system

-- check of voltages and currents

-- perform the sequence of tests to check detector performance (at two different temperatures – warm +22^{0}C & cold -10^{0}C)

Analog signal sampled by the FED



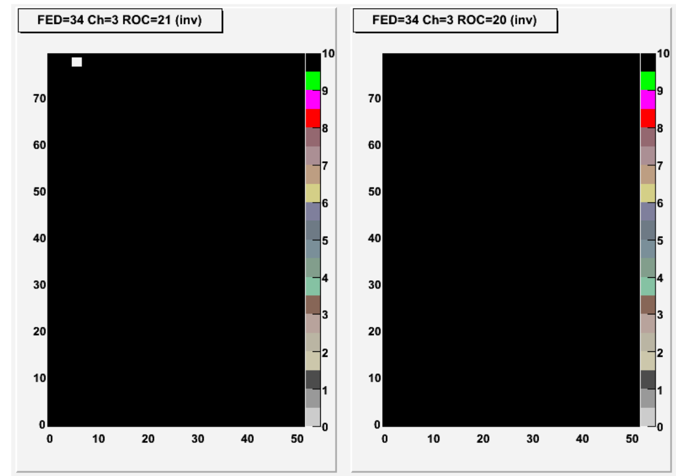


Pixel Alive Test

❖ The functionality of each pixel is checked by inducing a signal via an internal calibration capacitance:

--First, check that the masked (disabled) pixel does not respond. Second, for the enabled pixel 10 calibration signals are sent and no of output signals registered.

-- The pixel is fully working if all signals are registered and defective if no output signal.

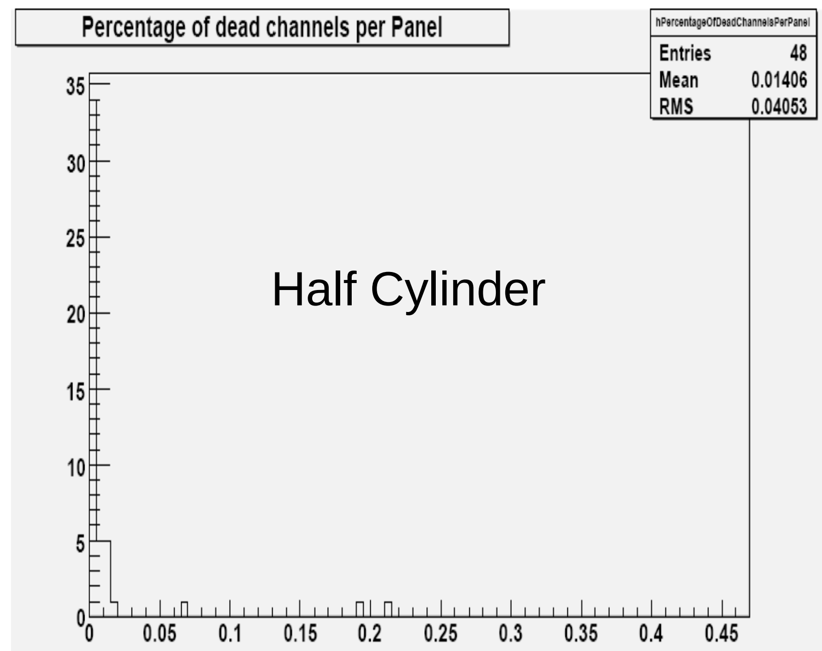


❖ Results were very encouraging

-- Negligible no of dead channels, roughly <0.4%.

-- The few dead cells are distributed randomly among modules (usually the edges & corners of ROCs) with no dead ROCs.

-- The results matched with the FNAL data taken during production

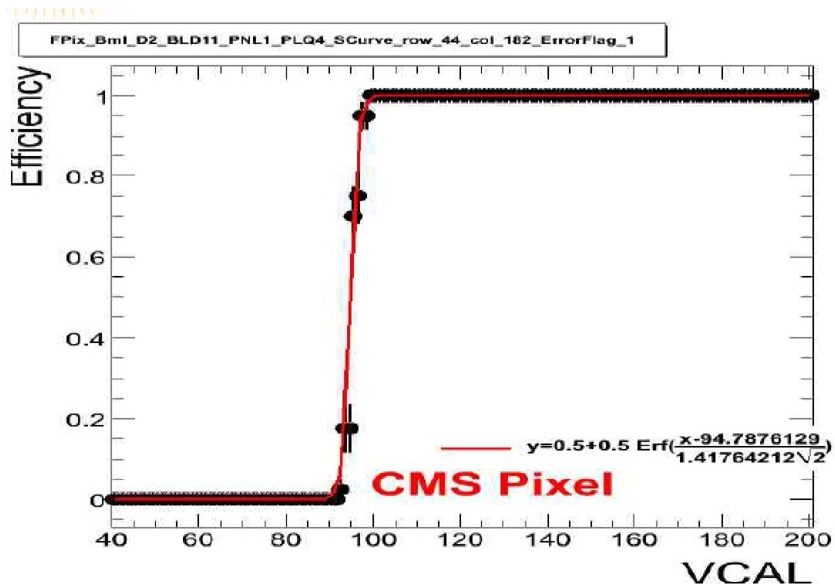


S-Curve Calibration

❖ Test designed to determine the threshold and noise of each pixel.

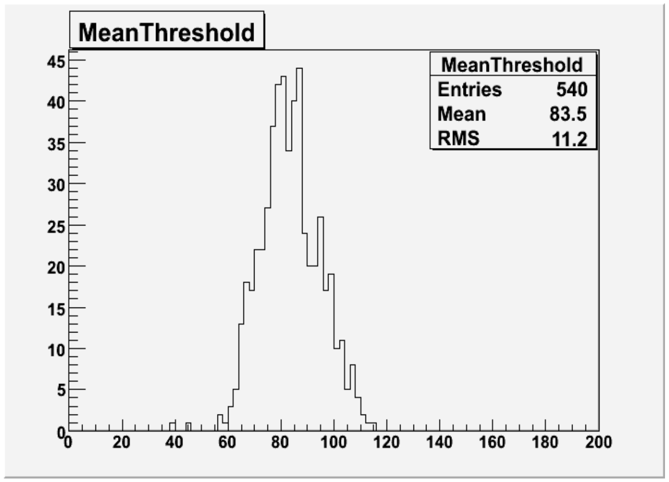
-- calculate efficiency vs amplitude of the calibrate signal
-- fit the S-Curve with errorfunc. turn-on $\rightarrow$Threshold, width$\rightarrow$Noise
-- VcalLow = 40 to 200 in steps of 1, 40 triggers, Pulsed cells = 100 (middle of ROC), Pattern = One cell at a time

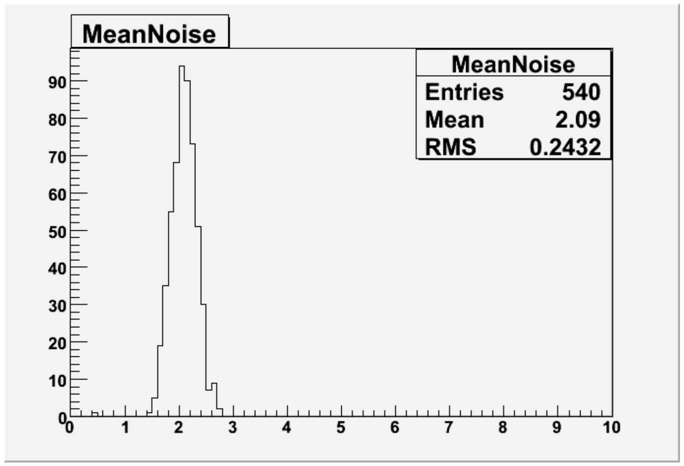
❖ Noisy pixels may flood the readout system with a high rate of fake hits and cause significant dead time and data losses. Therefore, the thresholds of such pixels must be increased or masked completely.



S-Curve Analysis Results

Run type	Mean noise [e⁻]	rms [e⁻]	Mean threshold [e⁻]	rms [e⁻]
HC-Z1				
warm	109	14	4871	494
cold	93	11	7107	787
HC-Z2				
warm	108	13	4868	485
cold	98	10	4542	481
HC+Z1				
warm	119	32	5914	889
cold	100	11	4683	559
HC+Z2				
warm	111	13	5208	558
cold	101	11	4858	566





- The detector noise performance as expected from FNAL production
- The overall noise is ~110e to be compared with a signal of ~22000e.
- Noise decreases on cold runs (as expected).
- Noisy cells: Noise > 4 Vcal (~260e), negligible

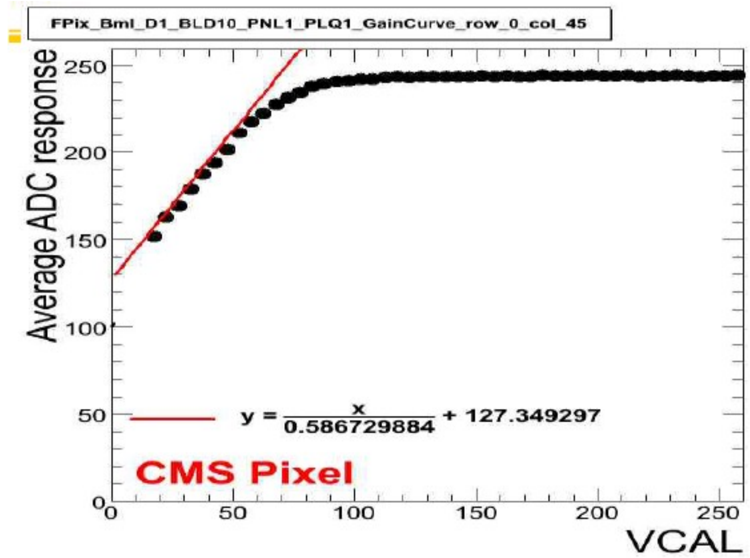
Gain Calibration

❖ Test designed to determine the gain and pedestal of each cell. The gains and pedestals are used to convert the charge collected by pixels & measured by ADC counts to electrons.

-- inject various amplitudes of calibrate signal and measure ADC response

-- Fit the resulting distribution by a linear function: slope→gain, offset→pedestal

-- VcalHigh = 0 to 255 in steps of 5, 10 triggers, Pulsed cells = all, Pattern: One cell at a time.



Run type	Mean gain [ADC/Vcal]	rms [ADC/Vcal]	Mean pedestal [Vcal]	rms [Vcal]
HC-Z1 (modules from 10 to 12)				
warm	0.54	0.23	86.1	2.9
HC-Z2 (modules from 7 to 12)				
warm	0.75	0.19	102.8	2.2
HC+Z1 (all modules)				
warm	0.65	0.2	86.6	2.3
HC+Z2 (modules from 10 to 12)				
warm	0.66	0.25	85.9	2.9

Important Tests

1. Magnet Test at Fermilab (A0 expt. area)

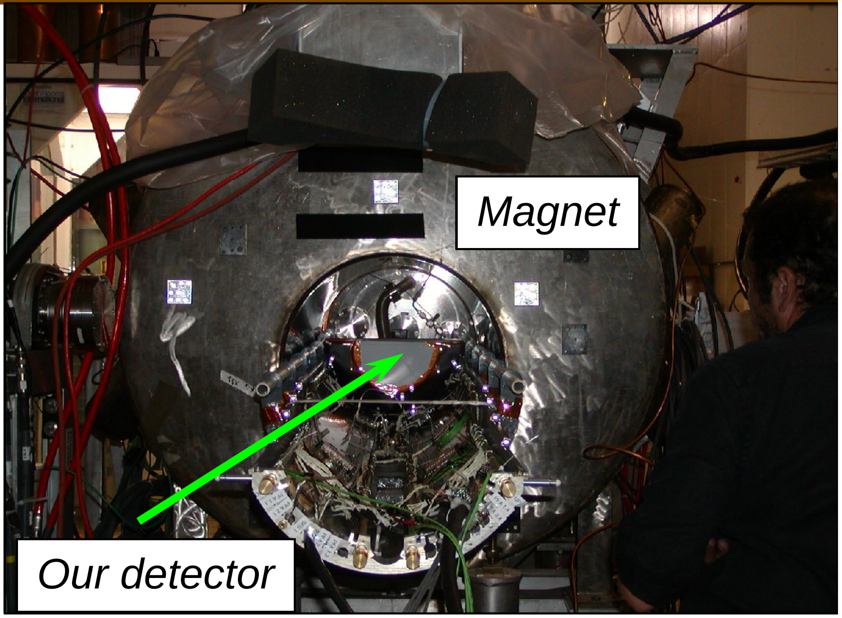
To test the behavior of the electronics and mechanics in a 4 Tesla magnetic field:

✓Monitor possible mechanical stress leading to movements due to B-field ramp-up and ramp-down

✓Test possible vibrations of wire-bonds induced by different trigger frequencies

✓Measure general performance (noise, gain, etc…)

The detector performed as expected and no movements were detected



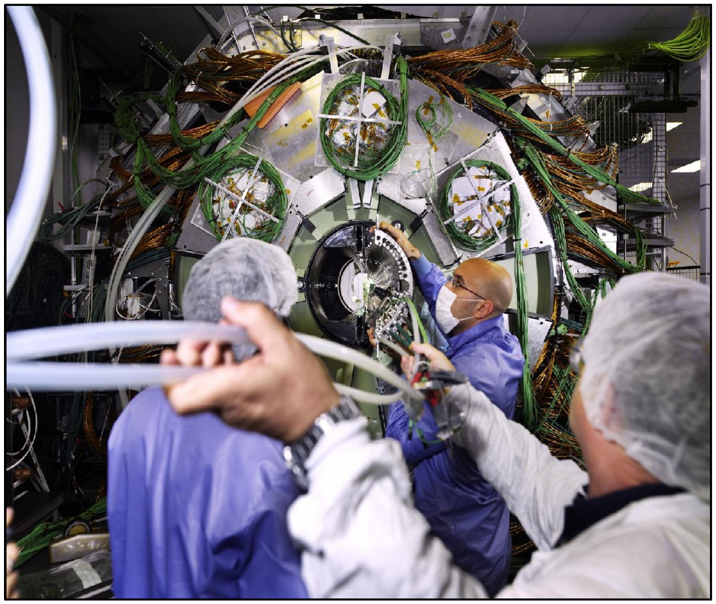
2. CMS Strip-Pixel Integration Test at Tracker Integration Facility (CERN):

The pilot FPix detector was inserted into the full micro-strip tracker:

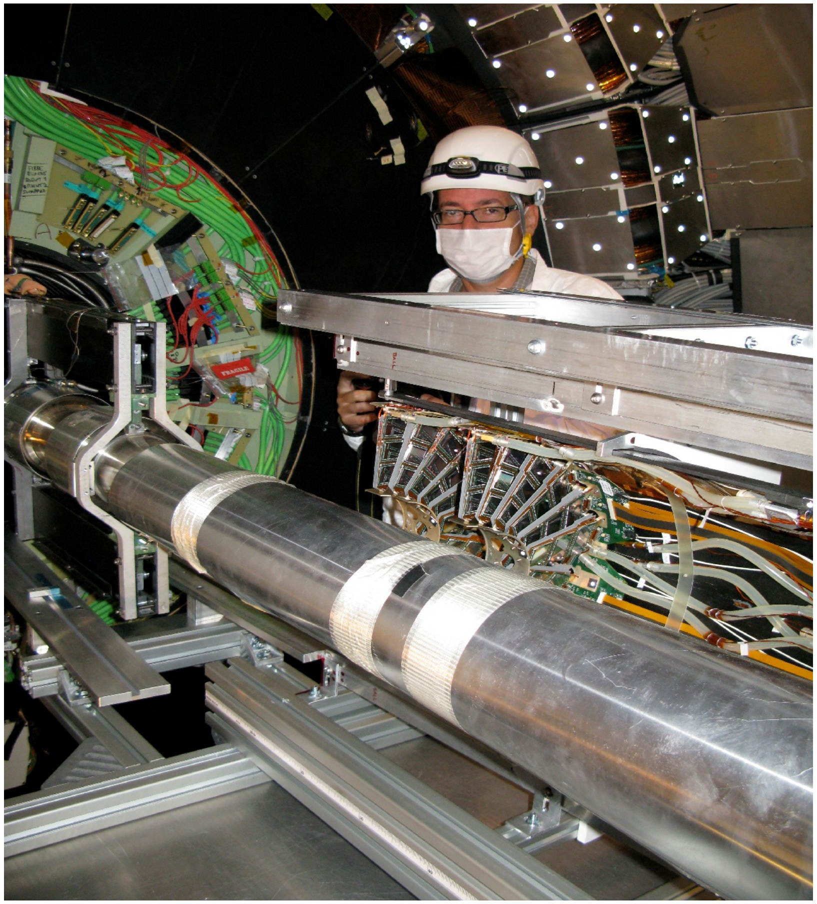
✓Learn about the insertion mechanics, electronics and software

✓Verify that noise was not injected by the strips into the pixel system and vice versa

✓No evidence was found of any degradation in performance or interference between pixels & strips.



Installation : July 2008



Detector installation after the installation & bake out of beam pipe.

FPix insertions tests were crucial for the smooth installation.

⇒FPix Insertion (July 29-31, 2008) after BPix Insertion (July 23 -24),

⇒Aug 7, 2008 lost access to the pixel bore and connection area

Commissioning at P5

❖ The goal of the FPix commissioning after installation was to prepare the detector for data taking with CMS.

--All connections (e.g. cooling, fibers, power, etc) thoroughly checked & properly mapped.

-- Fully functional detector control system (DCS) which allows to operate the detector in a safe mode.

-- The detector operates without interfering with other sub-detectors.

-- Data Quality Monitoring (DQM) in place to monitor the detector performance

-- Perform necessary set of calibrations to ensure the functionality of the detector.

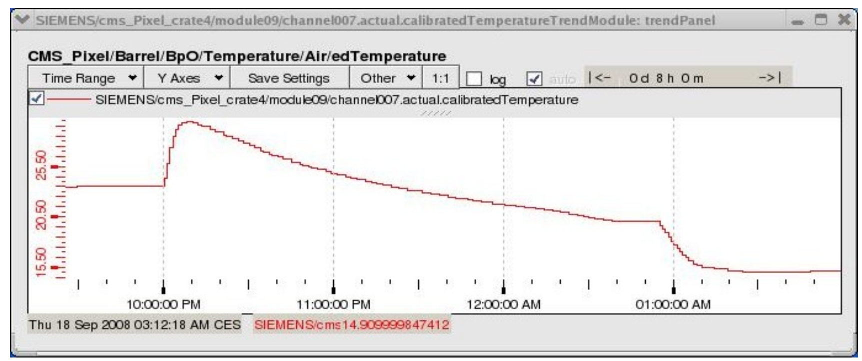
Forward Pixel Detector Health:

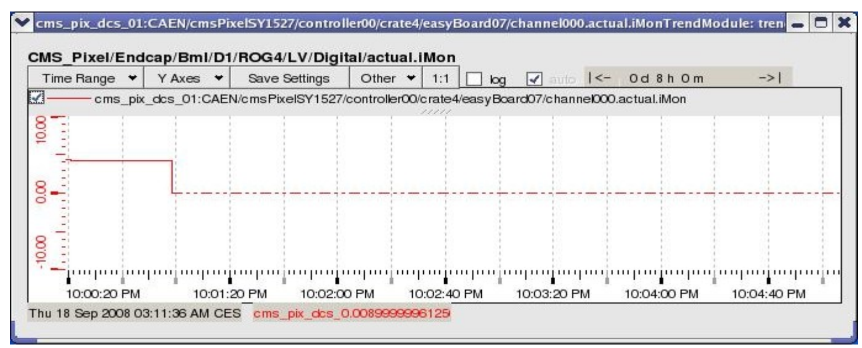
1. During Commissioning here at CERN
   - 100% of the readout chips were working
2. During transportation we lost one module: ***8 readout chips (broken HV wirebond)***
3. After loosing access to the detector and to our connection area:
   - We lost one sector: ***135 readout chips (short on LV digital power line)***
   - We lost all the modules belonging to the outer radius of one sector: ***93 readout chips (short on HV)***
   - We lost a "petal": ***24 readout chips (small/bad analog signal)***

Up to now: (4320-(135+93+24+8))/4320 = *93.98%* of the Forward Pixel detector is *ok (0% lost before installation, 6.02% lost after installation)**

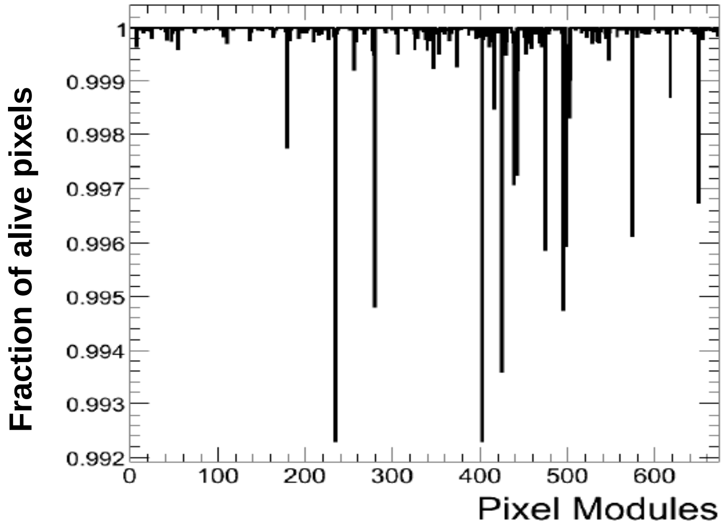
Pixel Detector Control System

Responsible for the safe operation of the pixel detector
→ Monitor temperature and humidity values
→ control and monitor the high and low voltages provided by the CAEN power supplies and to monitor their currents.
→ Monitor the state of the safety interlock logic system which automatically shuts-off the power in case either temperature or humidity values represent a thread for the safe operation of the CMS Pixel detector.



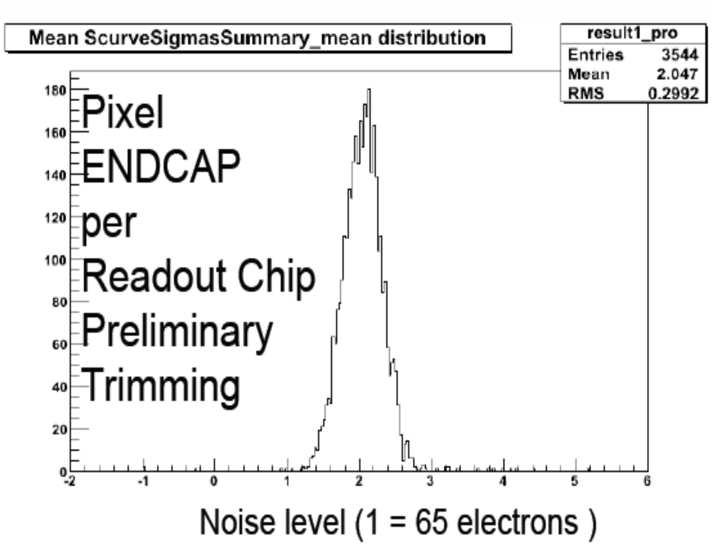


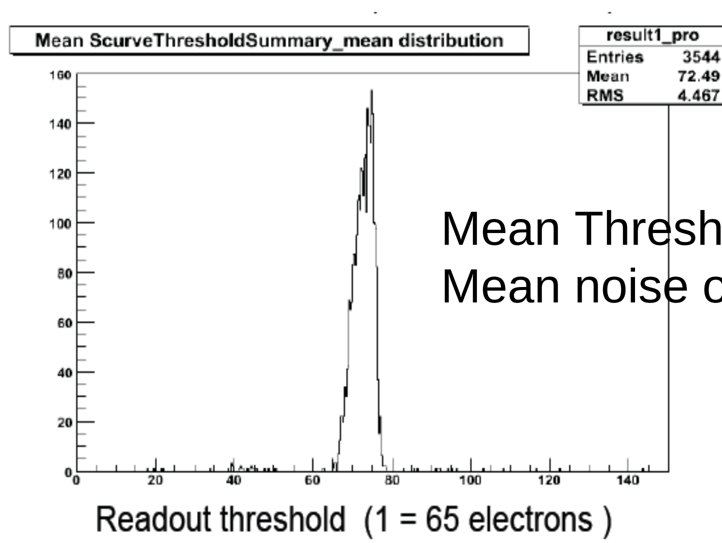
Detector Performance



❖ Pixel Alive Results very encouraging:
The fraction of absolutely dead cells tops out at ~ .008, equivalent to, at most, one dead double column on a ROC.

S-Curve Results: Noise & Threshold

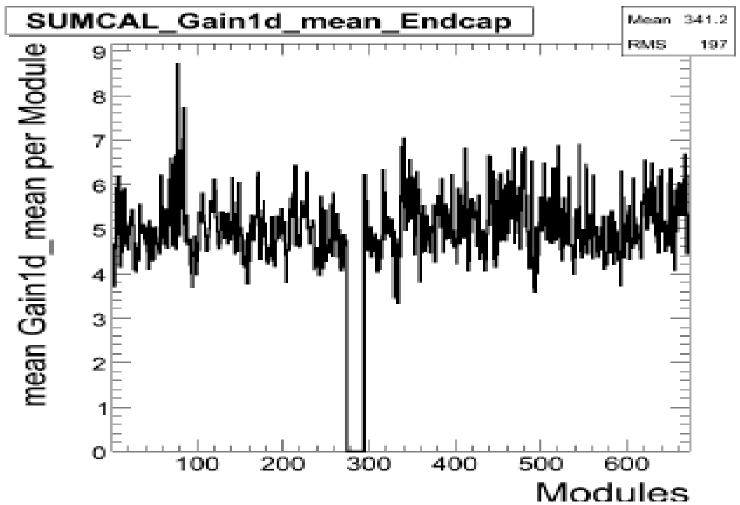


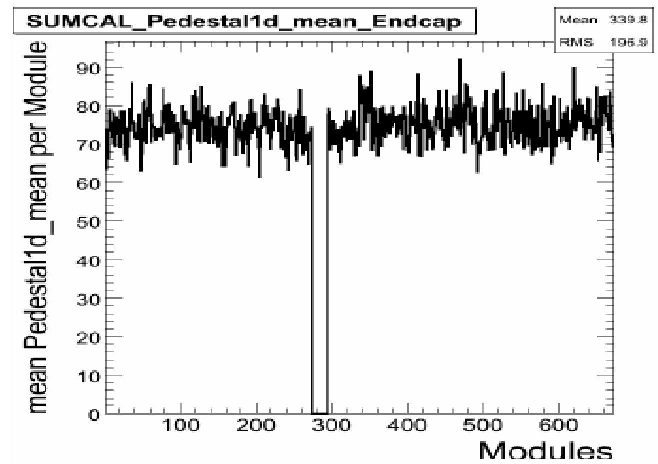


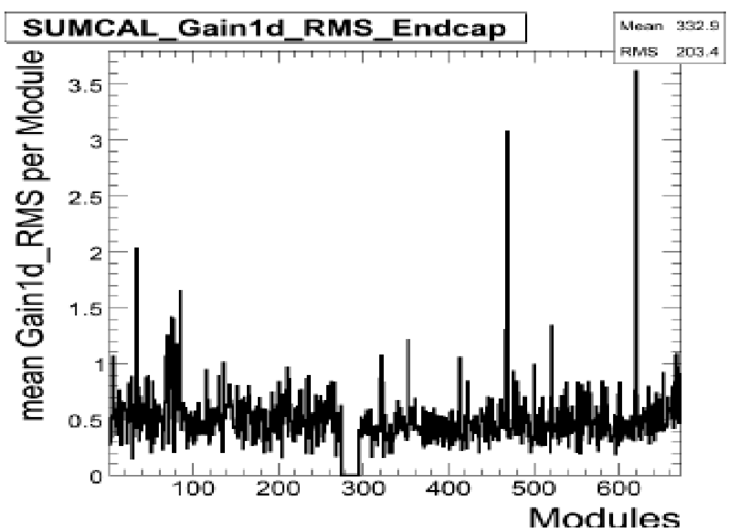
Mean Threshold of ~4700e
Mean noise of ~130e

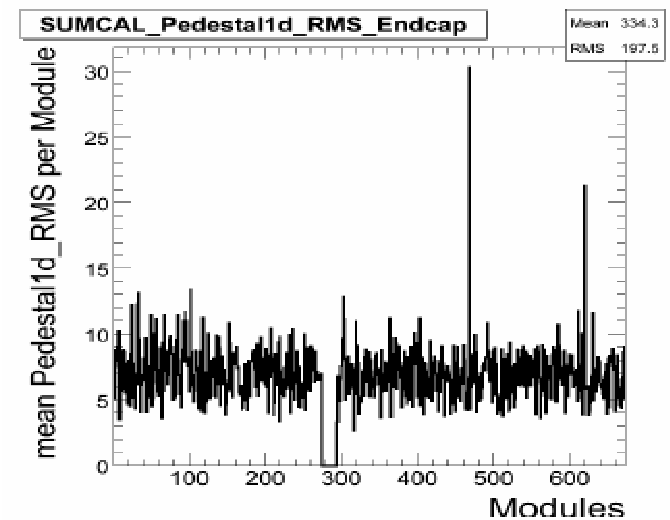
Mean Gain and Pedestal

Preliminary Results

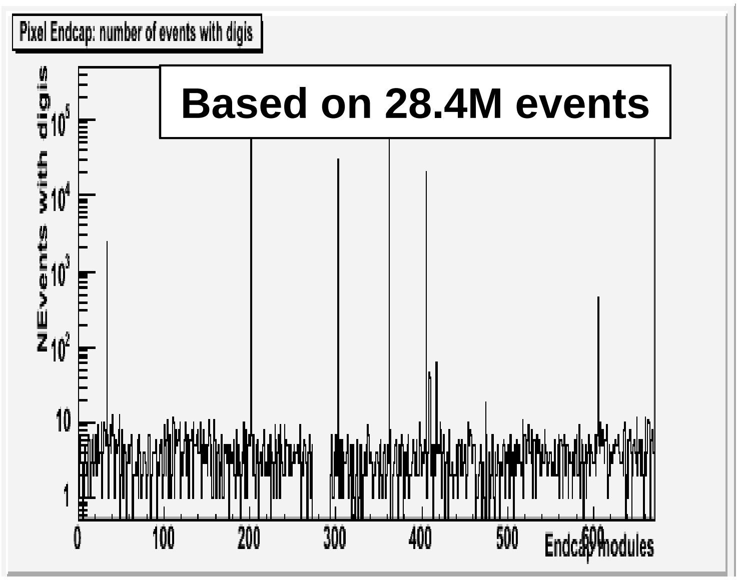








FPix in Global Cosmic runs



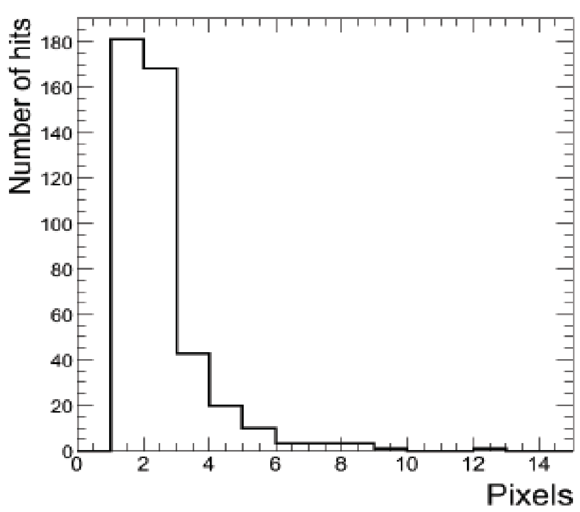
Cosmic run at Zero Tesla (CRUZET4 : Aug 18-25)

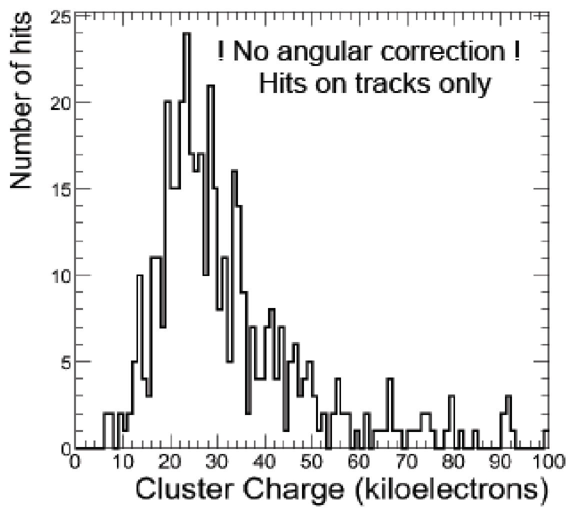
-- Successful first operation of both pixel partitions together with Tracker and other sub-detectors. S**table running, c**ollected ~35 M events with BPix+FPix (45.2 M FPix only)

-- remarkable since installation was just a month before. Previous global runs had just 1 FED channel, now 1344.

-- Established workflow of data analysis

-- Obviously the beginning but a great start.

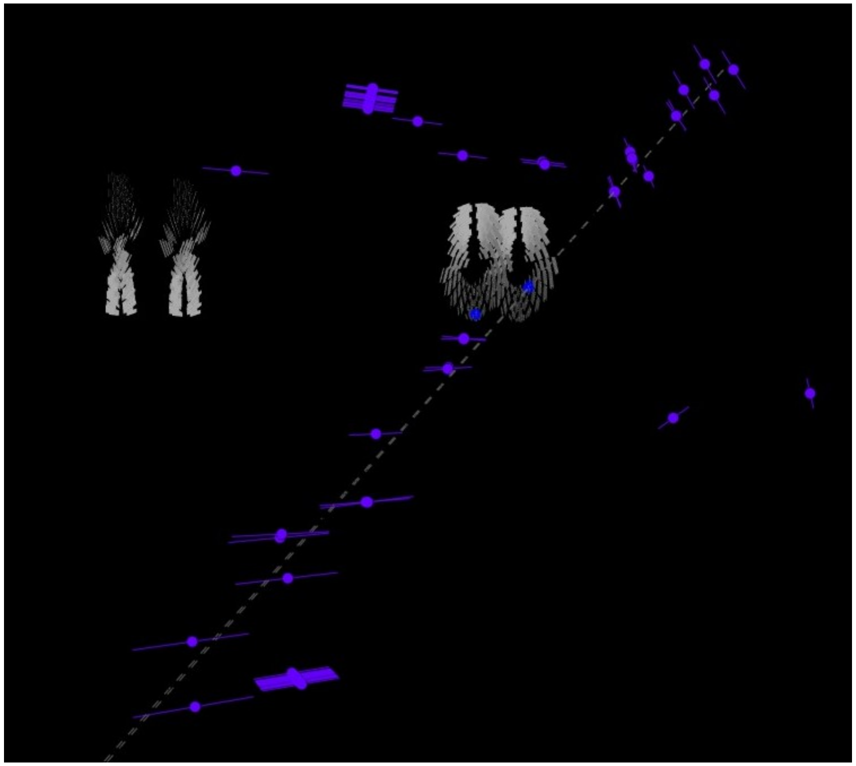


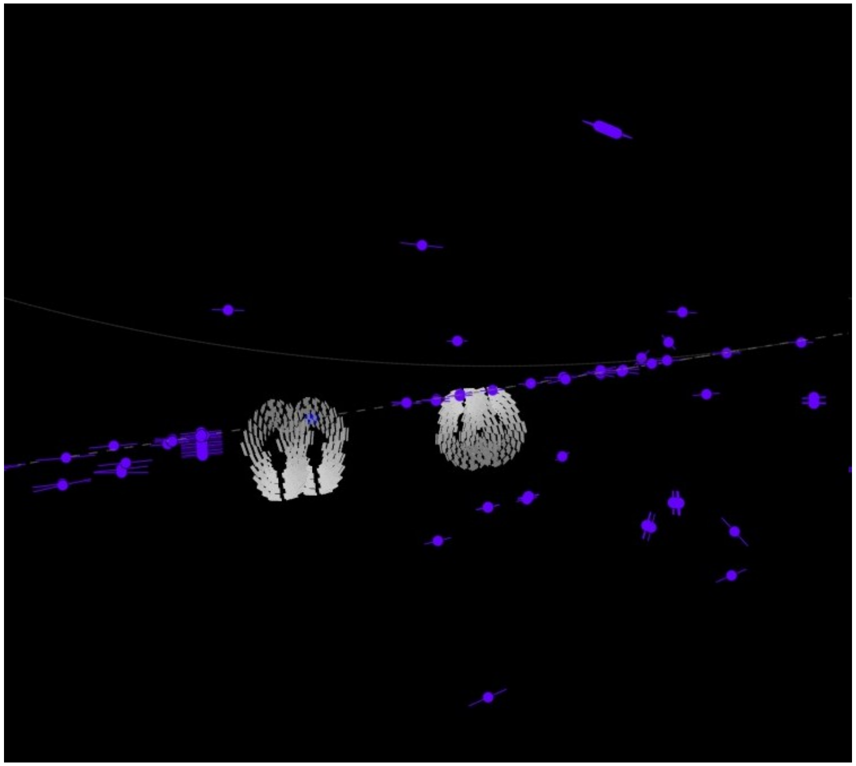


Most clusters: one or two pixels

Cosmic Event Display

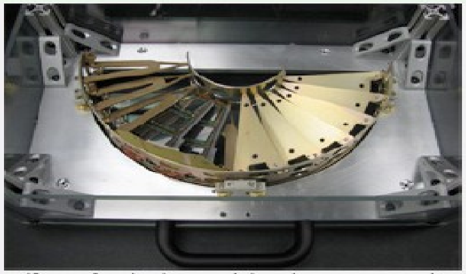
FPIX hits on tracks reconstructed in the strip tracker





Long Journey

The Forward Pixel Detector (FPix)



Half-ring for the '07 module. There are 6 cooling channels, two of which have active detectors. The other 6 locations are occupied with dummy panels.

The construction of the Forward Pixel Detector, FPix, is a collaboration between 17 US universities, the University of Milano/INFN, and Fermilab. There are two "disks" on each side of CMS, located at 34.5 and 46.5 cm from the interaction point. Each disk covers a radius of 6 to 15 cm from the beam

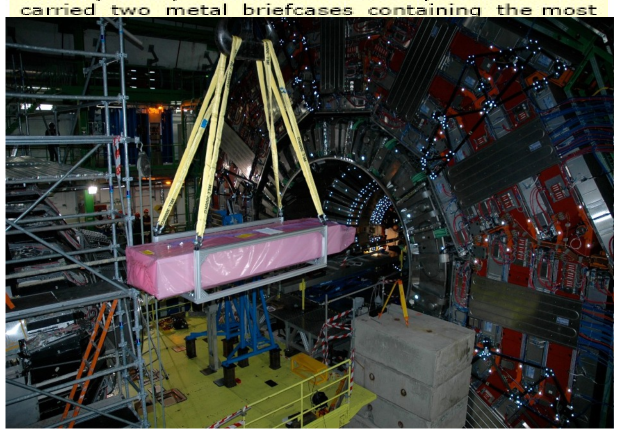
coverage, will be installed for the 2007 pilot run. This "commissioning module" is being assembled now. The first figure shows one of the half-rings for the '07 detector. Only two blades are populated with pixels. The second figure shows the half-cylinder for the '07 detector. This module will be completed and will be sent to CERN around January 15. It will be recommissioned in the CERN Tracker Integration Facility (TIF, building 186). The full detector will be completed in late summer of 2007.

CMS Pixels Group sees big picture with first shipment

Members of the CMS Pixels Group with their first completed half-cylinder, one of four for the CMS Pixels detector.

Last Friday morning, dozens of CMS Pixels group members at Fermilab celebrated the news that the first of the four components of the pixels detector had made it safely across the Atlantic to CERN. "This is a big milestone for us," said Simon Kwan of the Particle Physics Division's CMS department. "For CMS, this is a major piece of equipment, and to ship this to CERN successfully is thrilling."

University of California at Davis physicist John Conway and post-doc Ricardo Vasquez had hand-carried two metal briefcases containing the most



US CMS completes forward pixels detector

Two Fermilab PPD technicians, Dave Butler and Wanda Newby, traveled to CERN to install the CMS forward pixels detector half-disks that were recently completed at Fermilab. The actual half-disks are seen in their installed positions.

The CMS forward pixels detector group. The group recently completed the last two half-disks. The Pixels detector will contain four half-cylinders, assembled upstream and downstream of the proton-proton LHC interaction point. Inside each cylinder will be two half-disks filled with pixel detectors called plaquettes mounted on plates. The pixels will track charged particles flying out of the experiment.

Summary

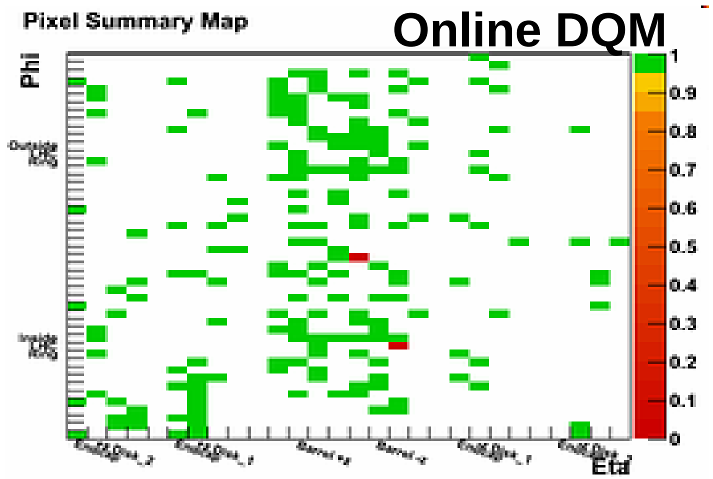
- The commissioning of Forward pixel detector showed that the detector has the excellent performance it had during production phase

  -- negligible no of dead channels

  -- average noise ~130e compared to signal of 22000e

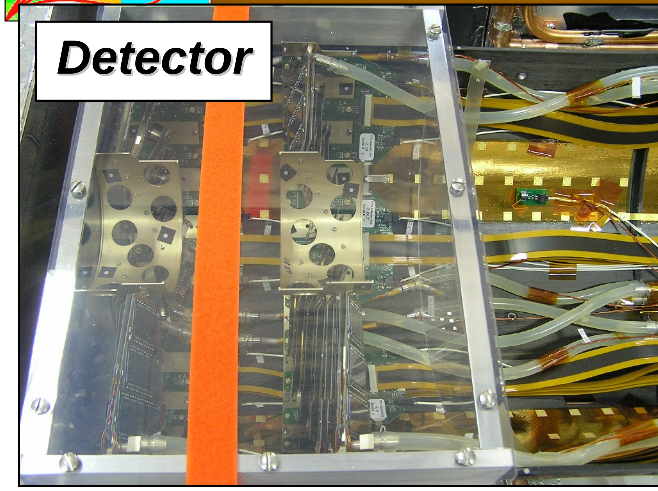
- Successfully installed the detector into CMS and commissioned thereafter – even within the short amount of time available
- FPix has been fully integrated with BPix and took cosmic data in global runs with other sub-detectors just a month after installation.

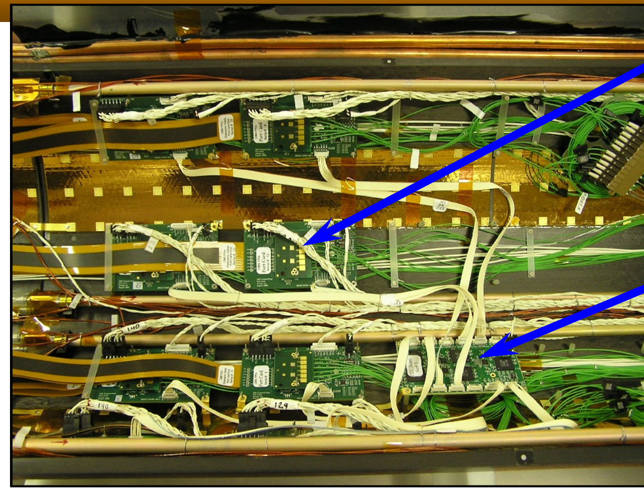
•Looking forward to successful operation in physics data taking after the commissioning of stable beam in the LHC machine.



Backup slides

Inside the FPix Detector





Portcard:

•AOH, DOH, Delay25, TPLL, DCU, Gatekeeper

Communication & Control Unit (CCU):

•Handle data to/from portcards

- **Sub-detector connected to the same power line (SECTOR): 6 panels = 135 ROCs**
  - **Each panel is connected to its own readout line: 1 panel = 21-24 ROCs**
- **Each half-cylinder has 8 SECTORS**

Gnd strip

Power cables

Power filter boards

Cooling lines